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An overview of hydraulic systems in wave energy application in China

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ABSTRACT

Wave energy is being increasingly regarded in China as a major and promising resource. There are many different ways to convert wave energy to electricity and some other energy. Hydraulic systems are used most widely in some of them to realize this conversion. An overview of hydraulic systems in wave energy application as well as the relevant technologies in China is given in this article. Some basic principles are presented, assessment and advices are shown for each category. Some suggestions of the outlook of hydraulic systems in wave energy application are also given.

Contents

1. Introduction

China's energy requirement is estimated to rise considerably in near future with its rapid economy development [1]. However, lack of fossil fuels and low energy efficiency further intensified China's energy consumption, made the situation even worse.

The energy from ocean waves is the most conspicuous form of ocean energy, The extraction of energy from the waves can be a viable solution to the enormous power requirements of a country like China having a vast coastline of more than 18,000 km and a sea area of more than 3,400,000 km^2 with abundant ocean energy resources. So developing wave energy bears enormous strategic significance for China's sustainable development, the utilization of wave energy could cover a modest part of the energy demand in China, and moreover, it could ensure energy security and optimize energy structure of China [2].

The possibility of converting wave energy into usable energy has inspired numerous inventors. The research and development of wave energy in China started in the late 1970, which was performed mainly at the Guangzhou Institute of Energy Conversion (GIEC) under the sponsorship of Chinese government, in co-operation with other national and international research institutions [3]. The number of patents about wave energy conversion devices in China has exceeded 1500 so far [4]. Most of the devices are very small so far. A conspicuous difficulty is related to the conception of the power take-off mechanism (PTO) of wave energy converter (air turbine, power hydraulics, linear electrical generator or other) which should allow the production of usable energy [5]. The problem here lies in the variability of the energy flux absorbed from the waves, in several time-scales: wave-to-wave (a few seconds), sea states (hours or days) and seasonable variations. Naturally, the survivability in extreme conditions is another major issue [5,6].

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The situation was dramatically changed by the introduction of hydraulic systems in wave energy applications, because hydraulic system has the characteristics of large transmission power and torque with low-frequency, fast frequency response, hydraulic overload protection and so on, which is very adapted to waves with the characteristics of large-power and low-frequency.

As one class of PTO, although hydraulic system currently shares only part of the ratio in wave energy application in China, it has great potential for development. This article makes investigations and analysis about wave energy's utilization and situation in China, especially the hydraulic systems used in these applications.

2. Hydraulic system principles for extraction of wave energy

The physical law of conservation of energy requires that the energy-extracting device must interact with the waves such as to reduce the amount of wave energy that is otherwise present in the sea [7]. Wave energy conversion can be considered a very suitable application for hydraulics. Waves apply large forces at slow speeds and hydraulic systems are suited to absorbing energy under this regime.

Hydraulic systems have many favorable characteristics and there are a couple of principles used to realize this conversion by means of hydraulic systems in China. Typical system consists of pumping hydraulic cylinders and hydraulic motor which rotates an electric generator. Back-and-forth movements of waves are first converted to hydraulic energy with double acting one or two rods hydraulic cylinders. Hydraulic energy is then converted to mechanical rotational energy with fixed or variable displacement hydraulic motors [8]. Because the motion of pumping hydraulic cylinders is periodic and the velocity varies greatly, some damping and load control method has to be used [9,10].

Fig. 1. 50 kW off-grid oscillating water column in China.

The variations of wave power cause the basic problem from hydraulics point of view. Because the flow from the hydraulic cylinder varies between the zero and the maximum value, some balancing system is required in order to guarantee the continuous rotation of the electric generator [8,11]. So cheap and available high-pressure gas accumulators are applied on these purposes, which make it a simple matter to achieve short-term energy storage, necessary to achieve the smooth electricity production required for a marketable machine.

3. Development status of hydraulic systems in wave energy application in China

In China, there is a large amount of ongoing work on wave energy schemes, especially the hydraulic systems in wave energy application, which cannot be done justice in a brief overview. For ease of presentation, the activities will be divided between the technologies suitable for deployment on the shoreline, near the shore and offshore [12].

3.1. Shoreline devices with hydraulic PTO in China

These devices are fixed to or embeded in the shoreline itself, which has the advantage of easier maintenance and/or installation. One major class of shoreline device is the oscillating water column (OWC). Fig. 1 shows a 50 kW off-grid OWC in China developed by GIEC with the project supported by the high Tech Research and Development (863) Program from 2002 to 2006, which extracts power from waves by an oscillating buoy using the pressure differences of crests and troughs.

As shown schematically in Fig. 2 [13], the absorbed wave energy is converted into hydraulic energy by the plunger pumps, a pressure-maintaining storage device then stabilizes the hydraulic energy, and then some of the stabilized hydraulic energy is converted into stable electricity output by a generator driven by hydraulic motor and the other is consumed by the desalinator. Real sea experiments showed that conversion efficiency of the hydraulic PTO system is higher than 60%, the total system efficiency is about 50%, with the help of hydraulic PTO system, the output power can be used directly, the quality of which is not

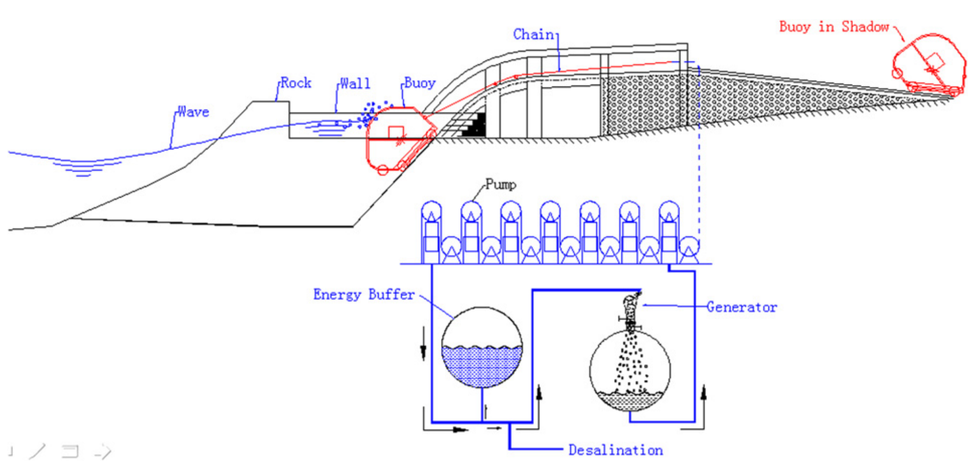

Fig. 2. Working principle of the 50 kW off-grid OWC wirh hydraulic PTO.

inferior to that of the diesel generator [2,13]. The energy consumption of the system itself is only 0.4 kW and the system can work well in small wave conditions. Both conversion efficiency, stability of output and energy consumption of itself had reached the world advanced level; it was the first wave energy system that can steadily generate electricity independently with the electricity grid or other power system in China [2].

The other main shoreline device in China is the 30 kW pendulous wave power plant (as shown in Fig. 3) set up by National Ocean Technology Center in Daguan island of Aoshanwei town, Jimo, Qingdao, Shandong province [14]. The pendulous wave power plant consists of a rectangular box, which is open to the sea at one end. A pendulum flap is hinged over this opening, so that the actions of the waves cause it to swing back and forth. This motion is then used to power a hydraulic pump and generator (Fig. 4) [6,12]. The plant puts out more than 800,000 kWh per year since it started working in September 1999. So far, the plant is still working well as the power supplier of 120 islanders of more than 30 families [4,14].

3.2. Near shore devices with hydraulic PTO in China

The main prototype device for moderate water depths (i.e. <20 m) in China is the 5 kW wave energy converter of inverse pendulum developed by Zhejiang University (Fig. 5). In this case the big plate is hinged to the bottom of the sea and it is moved by bottom waves. The two cylinders are installed between the plate with symmetry about the vertical axis and the sea bottom linked by hinged joints, and aligned with the wave direction. The incident wave interferes with equally large plane waves radiating in opposite directions from the symmetrical two-dimensional, then this swinging flap can absorb at most half of the incident wave power [15].

The wave induced motion of these joints is resisted by the two hydraulic rams, which pump high-pressure oil, and the high-pressure oil is fed into a large hydraulic accumulator to provide some energy storage before being used to drive a hydraulic motor and generator. As other devices that reached full size, the wave energy converter of inverse pendulum was the object of a detailed development program over several years that included theoretical/numerical modeling and physical model testing at several scales. Plant tests of a full-sized prototype (2 m width, 1.6 m height, 5 kW rated power) took place in 2010 in Shanghai (Fig. 5), and the sea trial will follow in the near future.

The simplified hydraulic schematic diagram of the wave energy converter of inverse pendulum is shown in Fig. 6. The hydraulic cylinders with four check valves acts as a pump, and the fluid via control manifolds, into high-pressure accumulator for short-term energy storage. In this case the hydraulic motor rotates one direction and in principle its displacement can vary between the zero and the maximum. The variable displacement

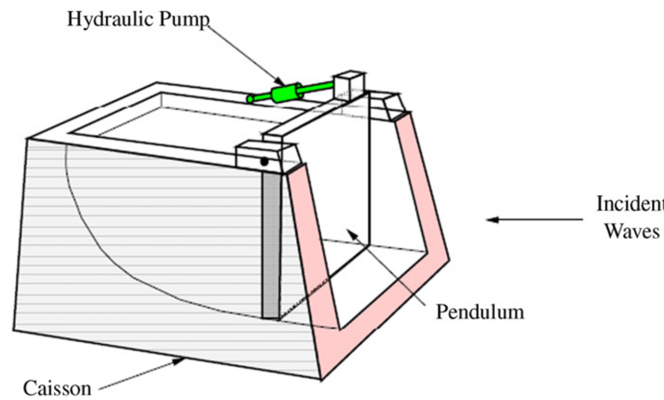

Fig. 4. Working principle of the pendulous wave power plant wirh hydraulic PTO.

Fig. 5. 5 kW wave energy converter of inverse pendulum in China.

Fig. 3. 30 kW pendulous wave power plant in China.

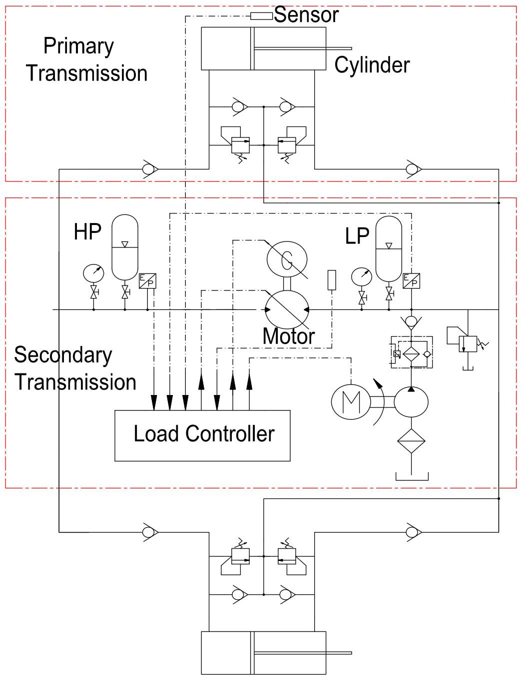

Fig. 6. Simplified hydraulic schematic diagram of the wave energy converter of inverse pendulum.

Fig. 7. The 10 kW floating nodding-Duck being sea trial in China.

hydraulic motor use the smooth supply of high-pressure fluid from the accumulator rotates the electric generator which supplies power to stand-alone power system.

The hydraulic PTO of the wave energy converter of inverse pendulum consists of the primary and secondary transmission, which can be seen as two separate parts [11]. The primary transmission, consisting of the two hydraulic cylinders and their controls, converts the work done by the waves on the swinging flap to stored energy. The secondary transmission, consisting of hydraulic motor coupled to electric generator, converts the energy stored in the hydraulic accumulators into electricity transmitted to shore. This separation, provided by the high-pressure accumulator, damps pressure oscillations and allows efficient absorption over a large range of incident power [16].

In the hydraulic PTO of the wave energy converter of inverse pendulum, whenever a chamber is pressured it exchanges fluid directly with storage accumulator, which represent much of the available wave energy throughout the wave period with high efficiency, even at low incident wave powers.

3.3. Offshore devices with hydraulic PTO in China

If wave radiation from a two-dimensional body is sufficiently non-symmetrical, such as with a wave-maker in a wave channel or with a horizontal cylinder, which is submerged on open sea and moves in a circular orbit about a sufficiently eccentric axis, then all incident wave energy is potentially absorbable [15]. The 10 kW floating nodding-Duck in China improved on the famous Salter Duck was developed by GIEC (Fig. 7), which is a non-symmetrical wave-power device attempting to approach complete wave energy absorption.

The 10 kW nodding-Duck can pitch with respect to a horizontal cylindrical cylinder aligned with the wave crest direction, which mounted on the so-called spine with a hydraulic-electric PTO system (Fig. 8). The wave induced motion of the floating nodding-Duck pitching is resisted by hydraulic rams which pump high pressure oil through hydraulic motor via smoothing accumulators.

4. Hydraulic PTO of wave energy converters

Hydraulic systems are particularly suitable to convert energy from the very large forces or moments applied by the waves on slowly oscillating bodies (in translation or rotation). The wave energy converter can be designed with a resonant response matched to the dominant frequency of the wave climate in which it is to be installed, minimizing the reactive power requirements

Fig. 8. Internal structure of 10 kW floating nodding-Duck in China.

of the hydraulic PTO. The level of excitation transmitted to the resonant response can be controlled via the hydraulic PTO [11,17].

The hydraulic circuit of hydraulic PTO in wave energy application usually includes a gas accumulator system, consisting of a high-pressure accumulator and a low pressure reservoir. The gas accumulator system is capable of storing and releasing energy over a few wave periods, which can smooth out the very irregular power absorbed from the ocean waves [18]. Usually a set of high-pressure gas accumulators interconnected in parallel is required to provide a suitable smoothing effect to a full-sized wave energy converter, and may represent a significant part of the PTO capital cost [5,10]. The oscillation (translation or rotation) motion of the wave energy converter is converted into hydraulic energy by a hydraulic cylinder or ram (or hydraulic cylinders or rams). A fast hydraulic motor drives a conventional electrical generator. The most frequently used type of fast hydraulic motor in wave energy applications not only in China but also in the world is the axial-piston bent-axis variable-displacement motor with the rated power range from a few kW to about 1 MW and the operating oil-pressures up to about 350 bar [5,13], which can control the instantaneous flow rate accurately and conveniently.

Although the damping provided by the hydraulic PTO in wave energy application is highly non-linear. The oil flow rate admitted to the hydraulic motor should increase with the absorbed wave-power level, whose instantaneous value should be controlled to remain proportional to the pressure difference between the high-pressure and low-pressure accumulators [10]. This kind of PTO is highly suitable for phase control by latching of the control manifold in the hydraulic circuit, a simple latching control algorithm was proposed in Ref. [19].

Although there is little literature on the performance of recent sea-tested prototypes of wave energy converter equipped with hydraulic PTO in China, it appears that some concerns are related to high cost, low efficiency, poor reliability, poor stability and small scale.

5. Conclusions

In general, the wave energy conversion technologies especially the hydraulic conversion technologies have significantly advanced in China during recent years. The present situation in China shows that the development of the wide variety of hydraulic systems in wave energy application, from concept to full-scale sea trial stage, is a difficult, slow and expensive process.

Nevertheless, the potential market in China for the wave energy conversion technologies of hydraulic systems is large, while the priority for the wave energy converters with hydraulic PTO is to demonstrate their survivability and reliability. Certainly, both initial political and financial support is needed for their breakthrough.

Acknowledgments

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